Metal Pollution in Nigeria: A Biomonitoring Update

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Background. Heavy metal contamination has become a challenge in Nigerian cities.
Objective. This review updates our current understanding of the environmental health effects of metal pollution in Nigeria.
Methods. The review was conducted by systematically searching the databases of GOOGLESCHOLAR, MEDLINE, PUBMED CENTRAL, and PUBMED libraries for original research using search terms such as 'metal pollution in Nigeria', 'bio-monitoring of lead, cadmium, nickel and chromium in Nigeria', 'lead in Nigeria', 'cadmium in Nigeria', 'nickel in Nigeria, and 'chromium in Nigeria'.
Discussion. This review highlights the need for the study of the toxicological implications of chronic, low-level exposure to heavy metals in African markets. Elevated blood lead levels (BLLs) have been documented in Nigerian populations across all ages, socioeconomic classes, sex, etc.
Conclusions. There is a need to assess BLLs across populations in Nigeria by undertaking sound scientific studies using appropriate sample sizes and methodologies. In particular, information is needed on both non-occupational and occupational exposures to adults that may result in children being exposed. A comprehensive strategy is needed to reduce lead exposure in order to reduce the future economic and disease burden in Nigeria.
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Introduction

Nigeria is located in West Africa and shares land borders with the Republic of Benin in the west, Chad and Cameroon in the east, and Niger in the north, and its southern coast lies on the Gulf of Guinea on the Atlantic Ocean. Nigeria has a population of 152,217,341 (growth rate: 1.9%), birth rate of 36.0/1000, infant mortality rate of 92.9/1000, and life expectancy of 50.2 years based on the 2006 census.[1] According to the World Health Organization (WHO) comprehensive study on the Environmental Burden of Disease (EBD), 2.97 million people die each year in all 46 African countries combined, including Nigeria, due to environmental risk factors.[2,3] Most of these deaths are preventable because they are associated with air and water quality, sanitation, and hygiene. Solid waste, built up dumpsites, and inefficient urban run-off systems are major features of most cities in Nigeria. Open-air incineration and solid waste create hazards associated with environmental pollution. In an editorial in the African Journal of Environmental Science and Technology, the top ten environmental challenges of Africa were itemized as follows: water disinfection, air disinfection, solid waste management, lead poisoning, smoke pollution, dust pollution, pesticide pollution, drought and deforestation, petrochemical pollution, and physical injury.[2,3]

Heavy metal contamination has become a grave challenge in Nigerian cities. According to the African Journal of Environmental Science and Technology, lead poisoning is one of the top ten environmental challenges in Africa.[2,3] Pollution of air, soil, and water has been a major factor in the introduction of heavy metals, such as cadmium, lead, and mercury in foodstuff. The presence of heavy metals in the ecosystem may arise from rapid industrial growth, advances in agricultural chemicals, or the urban activities of human beings.[2,3]

Many serious health concerns may arise from the uptake of heavy metal contaminated food. A decrease in immunological defenses, intrauterine growth retardation, impaired psycho-social behavior, and disabilities associated with malnutrition are just a few of the many health concerns.[4] In Nigeria, sparse human biomonitoring (HBM) data have been collected over the last few years in areas polluted with lead. There is a need to study the toxicological implications of chronic, low level exposure to heavy metals in African markets to help reduce lead exposure, lower the disease burden, and ultimately improve the future of the economy in Nigeria.

This review updates our understanding of the environmental health effects of metal pollution in Nigeria.

Abbreviations			
ASM	Artisanal and small-scale mining	*HBM*	Human biomonitoring
BLL	Blood lead level	*HPb*	Hair lead
CDC	Centers for Disease Control and Prevention	*HRW*	Human Rights Watch
		NPb	Fingernail lead
EBD	Environmental Burden of Disease	*WHO*	World Health Organization

Methods

Aim, Search Strategy, and Selection Criteria

The present paper provides an update on our current understanding of the environmental health effects of heavy metal pollution in Nigeria. The review was conducted by systematically searching the databases of GOOGLESCHOLAR, MEDLINE, PUBMED CENTRAL, and PUBMED libraries for original research using search terms such as 'metal pollution in Nigeria', 'bio-monitoring of lead, cadmium, nickel and chromium in Nigeria', 'lead in Nigeria', 'cadmium in Nigeria', 'nickel in Nigeria', and 'chromium in Nigeria'. These metals have a significant impact on public health in Nigeria. Search results were collated and studied, while systematically extracting results relevant to the review. Searches were not limited to time or place of research, but limited to publications available (originally or translated) in the English language from 1985 to 2012 as shown in Tables 1–4.

Results

A total of 649 articles were found. Ninety-two articles met the inclusion criteria for lead and eleven met the inclusion criteria for cadmium. In addition, five articles met the inclusion criteria for arsenic, nickel, and other metals like copper and zinc.

Environmental degradation, due to the simultaneous effects of old and new agents, is a major issue responsible for the worsening of health problems in sub-Saharan Africa.[4,5] Air pollution in major African cities is a significant challenge due to excessive traffic on poor roads and the use of obsolete cars. Industrialization, rapidly progressing around many sub-Saharan African cities, is often based on outdated machinery and highly polluting production, and relies on intensive exploitation of local resources and cheap labor.[6] All of these factors contribute to air and water pollution and disease-related occupational exposures. In the past, the majority of environmental health research in Nigeria has focused on lead (Pb), which still remains the most important of all the toxic heavy metals.

Sources of Pb in Nigeria

Studies have shown that Pb emissions in the air at ground level in Lagos, Nigeria are far higher than in other major cities such as London and New York, but are similar to those in Brazil or the Caribbean due to the amount of roadside traffic.[90] A study by Popoola et al. showed that heavy metal levels, including Pb, detected in dust in classrooms in Lagos, Nigeria were higher than the values for street dust obtained from residential areas in the metropolitan city of Kathmandu, Nepal.[7,8] In Nigeria, as in other sub-Saharan African countries, the entire population, but especially children, are vulnerable to Pb exposure because of the unabated use of leaded gasoline, the poor recovery and recycling of automotive lead-acid batteries, and up until the end of the 1990s, unregulated cottage industries associated with electronic waste recycling.[9-12] Socio-ecological and climatic factors also contribute to high levels of inhalation and ingestion of Pb-laden aerosols and dust.[13-16]

In Nigeria, phase-out programs have been initiated in order to reduce leaded gasoline use.[91] However, it is difficult to know how well these programs have been implemented. Prior to these phase-out programs, gasoline contained, on average, 0.66 μg Pb/L.[17] Several studies have indicated that airborne lead from gasoline is the primary exposure source for adults, fetuses, and children.[18] In Lagos, specific emissions of Pb exceed 164 kg/km2, representing approximately 20% of the 2.46 Gg of Pb emissions nationwide.[19] In addition, the ambient air concentration of Pb in Lagos ranges up to 9.58 μg/m3, exceeding the

Type of Sample	Lead (Pb)				
	Location of Sample	Reported Concentrations	Author	Year of Publication	Reference Number
Automotive Emissions	Lagos, Nigeria	164 kg/km2	Obioh et al.	1988	19
Leaded Gasoline	Nigeria	0.66 μg/L	Fakayode et al.	2003	17
Ambient Air	Lagos, Nigeria	9.58 μg/m3	Obioh et al.	1988	19
Drinking Water	Nigeria	0.01 mg/L 2.50 μg/g	WHO WHO	1983 1996	24 25
Soil	Nigeria	12,102 mg/kg	Orisakwe et al.	2004	27
Rice	Nigeria	4.31 μg/kg 19.53 μg/kg	Orisakwe et al. Orisakwe et al.	2012 2004	26 26
Cassava Beans	Nigeria	21 mg/kg	Orisakwe et al.	2012	27
Fruit	Nigeria	19.00 mg/kg	Orisakwe et al.	2004	27
Infant Formula	Nigeria	<25 mg/kg body weight	Ikem et al.	2002	31
Tap Water	Nigeria	0.13 ± 0.08 mg/L	Ignatius et al.	2012	40
Well Water	Nigeria	1.04 ± 0.19 mg/L	Ignatius et al.	2012	40
Borehole Water	Nigeria	0.78 ± 0.19 mg/L	Ignatius et al.	2012	40
Stream/River Water	Nigeria	0.83 ± 0.22 mg/L	Ignatius et al.	2012	40

Table 1a — Lead concentrations in environmental samples and food products

World Health Organization's (WHO) recommended annual average of 0.5 μg/m3.[19] Some studies have argued that completely banning leaded gasoline could significantly decrease Pb levels in the environment and in adults, children, and unborn fetuses.[20-22] A study by Huang et al. demonstrated that low-level prenatal Pb exposure to unborn fetuses can lead to decreasing intelligence quotient and delayed cognitive function in children.[23]

Soil, water, and foodstuff may contribute to the body burden of toxic heavy metals in Nigeria. The WHO's standard guideline values of Pb in drinking water and soil are 0.01 mg/l and 2.50 μg/g, respectively.[24-25] In 2012, Orisakwe et al. demonstrated that the estimated Pb intake for rice and cassava-based meals in Nigeria was 4.31 and 19.53 μg/kg, respectively.[26] Another study performed in Nnewi, Nigeria found that the Pb content in food and soil samples were also found to be very high, i.e., 19 mg/kg in fruit, 21 mg/kg in cassava, and as high as 12,102 mg/kg in certain soil samples.[27] The high reported Pb level is most likely due to absorbed Pb rather than surface contamination.[27] Studies have also shown that flaking of paints sold in Nigeria increases the environmental heavy metal burden.[28-29] Paints commonly used in Nigeria may contain high levels of Pb and other heavy metals, and due to poor hygiene, there may be cases of undocumented and unintentional ingestion.[30] Infant formula, canned and non-canned beverages, and pediatric

Type of Sample	Lead (Pb)				
	Location of Sample	Reported Concentrations	Author	Year of Publication	Reference Number
Blood Levels (1-5 yr)	Taiwan, China	5.86 ± 2.62 µg/dl	Yang et al.	1995	92
Blood Levels (children)	Nigeria	>10 µg/dl or >20 µg/dl 48.50 ± 9.08 ug/dl	Nriagu et al. Babalola et al.	2008 2005	54 55
Blood Levels (18-45 yr, exposed male auto mechanics)	Abeokuta, Southwest Nigeria	27.00 ± 1.05 to 48.90 ± 19.10 µg/dl 39.00 ± 4.00 µg/dl	Ademuyiwa et al. Orisakwe et al.	2005 2007	56 57
Hair Levels (18-45 yr, exposed male auto mechanics)	Abeokuta, Southwest Nigeria	17.75 ± 5.16 µg/g	Babalola et al.	2005	55
Fingernail Levels (18-45 yr, exposed, male auto mechanics)	Abeokuta, Southwest Nigeria	5.92 ± 3.30 µg/g	Babalola et al.	2005	55
Blood Levels (18-45 yr, non-exposed, male control subjects)	Abeokuta, Southwest Nigeria	50.00 ± 10.09 µg/dl 15.78 ± 2.84 µg/dl 17.00 ± 4.00 µg/dl	Babalola et al. Ademuyiwa et al. Orisakwe et al.	2005 2005 2007	55 56 57
Hair Levels (18-45 yr, non-exposed, male control subjects)	Abeokuta, Southwest Nigeria	14.30 ± 5.90 µg/g	Babalola et al.	2005	55
Fingernail Levels (18-45 yr, non-exposed, male control subjects)	Abeokuta, Southwest Nigeria	5.31 ± 2.77 µg/g	Babalola et al.	2005	55
Blood Levels (non-occupationally exposed pregnant women)	Niger Delta	40.00 ± 16.50 µg/dl 99.00 µg/dl	Ugwuja et al. Njoku et al.	2013 2012	58 59
Blood Levels (non-occupationally exposed non-pregnant women)	Niger Delta	27.7 ± 1.10 µg/dl	Adekunle et al.	2010	60
Human Scalp Hair	Southeast Nigeria	9.1 to 194.5 µg/g	Nnorom et al.	2005	62
Blood Lead, Traffic Wardens and Police	Oshodi, Dopemu, & Ojota in Southwest Nigeria	152.42 µg/dl 148.56 µg/dl 122.6 µg/dl	Osuntogun et al.	2007	63

Table 1b — Lead concentrations in human biological samples syrup are chief exposure routes for Pb poisoning in children.[31-33]

Although infant formula may be one of the chief exposure routes for Pb poisoning in children, the estimated daily intakes of Pb and Cd from infant formula were actually below the FAO/WHO Joint Expert Committee on Food Additives recommended provisional tolerable weekly intakes (PTWI) of 25 and 70 μg/kg body weight, respectively.[31] It has been reported that children are more susceptible to some heavy metal exposures due to their increased intestinal absorption and their lower threshold for adverse effects compared to adults.[34, 35] Pollutants may arise from raw materials used in production, poor quality production processes, adulteration of infant foods, and preparation of infant formula.[36] A number of non-traditional sources of Pb associated with elevated BLLs in Nigerian children include the use of lead-containing eye cosmetics and herbal medicaments.[37, 38] Imported glazed ceramics (e.g., drinking mugs, soup bowls, and cooking pots) in Nigeria have been reported to contain more Pb than those that are locally manufactured.[39] The mean (± SD) Pb levels found in tap, well, borehole and stream/river water have been reported at 0.13 (± 0.08), 1.04 (± 0.19), 0.78 (± 0.19) and 0.83 (± 0.22) mg/L, respectively.[40] The latter values greatly exceed the US EPA drinking-water Pb levels of 15 μg/L. Considering the challenge of maintaining a clean water supply, especially in rural communities where hand dug wells and streams serve as the source of potable water, drinking water may be a significant source of Pb exposure in Nigeria. Another major exposure to Pb is food, which is believed to account for over 60% of elevated BLLs in adults; air inhalation accounts for nearly 30%, while water accounts for 10%.[41] A study by Dioka et al. showed that petrol-based occupations are a major Pb exposure pathway for adults in Nigeria.[42] Other important sources of air-borne lead in Nigeria for both adults and children include burning garbage (i.e., domestic and industrial refuse, wood, paper products, plastics, discarded tires, battery casings, agricultural wastes, etc.) in open air (a common method of waste management), the use of wood fuel for cooking, and factories (including cottage industries) equipped with limited or no pollution control devices.[43,43] After deposition, some of the contaminated dusts are cycled back into the air, visible in trailing plumes of dust that accompany lorries in many parts of Nigerian cities. The Pb-contaminated dust becomes pervasively redistributed to residential areas, where children may come into contact with it.[45]

Excessive flooding and drought, the high price of farm equipment, and an atmosphere of economic instability have driven farmers in Nigeria to abandon subsistence agriculture and take up artisanal mining. Mining employs rudimentary and improvised techniques of mineral extraction and often operates under hazardous conditions. Artisanal and small-scale mining (ASM) are mostly undertaken by local people with a limited understanding of the long-term impacts on the environment and their health, as well as a limited capacity to mitigate the hazards. The failure to understand long-term impacts on health and avoid the hazards of artisanal mining were seen in 2010 in Zamfara State in northwest Nigeria with the death of at least 400 children as a result of lead poisoning. Human Rights Watch (HRW) described this tragedy as the "worst lead poisoning epidemic in modern history".[46]

Levels of Pb, Cd, and nickel (Ni) have been investigated in three highly popular seafoods in Nigeria; fish (*Tilapia zilli*), crab (*Callinectes sapidus*), and periwinkle (*Littorina littorea*), to evaluate the ecosystem health status in Ondo State, an oil-polluted coastal region in Nigeria. The study revealed that anthropogenic enrichment of Pb, Cd, and Ni could pose potential threats to the ecology and health of the area.[47] In a second study, Ihedioha and Okoye assessed the concentrations of Cd and Pb in the muscle, liver, kidney, intestine, and tripe of cows in Nigeria, and concluded that Cd was accumulated mainly in the kidney, while Pb accumulated mostly in the liver, and both toxic metals were above the maximum, international permissible levels in most samples.[48]

Human biomonitoring of Pb

Human exposure to Pb occurs primarily through a combination of inhalation and ingestion. The contribution of air-borne Pb comes mainly from vehicular exhaust from petroleum fuels containing alkyl-lead derivatives as the anti-knock agent, the burning of solid waste, and cigarette smoke.[49-51] Approximately 5–10% of ingested inorganic Pb is absorbed, while the majority is excreted in urine. Pb absorption increases with diets rich in fat and low in calcium, magnesium, iron, zinc, and/or copper.[52-53] Low dietary calcium tends to characterize the consumption pattern of most Nigerian families due to poverty.[52]

Widespread Pb contamination of the environment in Nigeria is consistent with the results of epidemiological studies demonstrating elevated BLLs in a large proportion of Nigerian children. In a recent study in Nigeria, one quarter of the children tested had BLLs >10 μg/dL and about 4% of the children tested had BLLs that exceeded 20 μg/dL.[54] Most Nigerian families of low socio-economic status maintain a diet consisting largely of cassava-based foods that are low in calcium. The lack of calcium could explain the higher mean BLLs in Nigeria when compared to Western nations that have a calcium-rich diet.

Type of Sample	Cadmium (Cd)				
	Location of Sample	Reported Concentrations	Author	Year of Publication	Reference Number
Infant Formula	Nigeria	<70 mg/kg body weight	Ikem et al.	2002	31
Chicken Eggs	Ibadan, Nigeria	0.07 mg/kg	Fakayode et al.	2003	17
Daily Intake of Local Feed	Ibadan, Nigeria	2.4 μg	Fakayode et al.	2004	17
Ground Water	Southwest Nigeria	0.24 to 0.36 mg/L	Adekunle et al.	2007	76
Airborne Cement Dust	Sagamu, Southwest Nigeria	0.004 to 0.026 g/m3	Gbadebo et al.	2007	77
Soil	Warri, Nigeria	7.605 to 24.194 mg/kg	European Union	2002	78
Hair Products/ Medicated Creams	Nigeria	0.553 mg/L	Ayenimo et al.	2010	79
Human Scalp Hair	Southeast Nigeria	0.4 to 6.6 μg/g	Nnorom et al.	2005	64
Paint Factory Workers	Nkpor, Nigeria	13.00 ± 1.00 μg/L	Orisakwe et al.	2007	57
Population	Southeast Nigeria	0.007 to 0.293 μg/dL	Ibeto et al.	2009	81
Blood Levels (men & women)	Spain	0.002 to 0.0324 μg/dL	Llobet et al.	1998	83
Blood Levels (adult)	New York	0.0077 μg/dL	Wendy et al.	2007	84
Plasma Level (male adults)	Ibadan, Nigeria	6.0 μg/dL	Arinola et al.	2008	85
Plasma Level (male adults)	Nkpor & Nnewi, Anambra State Southeast Nigeria	9.0 μg/dL	Orisakwe et al.	2007	57
Blood Level	Akure, Ondo State, Southwest Nigeria	0.76 μg/dL	Babalola et al.	2007	86
Blood Level (pregnant women/nursing mothers)	Southeast Nigeria	0.1 to 2.8 μg/dL (avg = 0.99 ± 0.64 μg/dL)	Ibeto et al.	2009	81
Blood Level (non-pregnant women)	Southeast Nigeria	0.1 to 2.9 μg/dL (avg = 0.80 ± 0.46 μg/dL)	Ibeto et al.	2009	81
Blood Level (pregnant women)	Bangladesh	0.012 μg/dL	Kippler et al.	2007	87

Table 2 — Cadmium concentrations in environmental samples, food products, and human biological samples

Type of Sample	Nickel (Ni)				
	Location of Sample	Reported Concentrations	Author	Year of Publication	Reference Number
Daily Intake of Local Feed	Nigeria	0.9 μg/person	Fakayode et al.	2003	17
Chicken Eggs	Nigeria	0.03 mg/kg	Fakayode et al.	2003	17
Human Scalp Hair	Nigeria	5.0 to 143.2 μg/g	Nnorom et al.	2005	62

Table 3 — Nickel concentrations in food products and human biological samples

Studies by Babalola et al. examined Pb levels from the blood, scalp, hair, and fingernails of male auto-mechanics (aged 18-45 years) from Abeokuta, Southwestern Nigeria.[55] Mean Pb levels from blood (BLL), hair (HPb,) and fingernails (NPb) of the occupationally exposed subjects were 48.50 (± 9.08) μg/dL, 17.75 (± 5.16) μg/g, and 5.92 (± 3.30) μg/g respectively, while the corresponding mean values for these parameters in control subjects were 50 (± 10.09) μg/dL, 14.30 (± 5.90) μg/g, and 5.31 (± 2.77) μg/g, respectively. Ademuyiwa et al. reported BLLs of 27.00 (± 1.05) - 48.90 (± 19.1) μg/g in exposed auto mechanics and 15.78 (± 2.84) μg/dL in unexposed control subjects.[56] These data are similar to those of Orisakwe et al. who reported BLLs of 39.00 (± 4.00) μg/dL in exposed subjects and 17.00 (± 4.00) μg/dL in controls.[57] According to both sets of researchers, the higher levels of Pb observed in test subjects compared with those of controls were attributable to environmental sources.

Ugwuja et al. reported non-occupationally exposed BLLs of pregnant women to be 40.0 (±16.5) μg/dL.[58] This value is lower than the 99.0 μg/dL reported by Njoku and Orisakwe.[59] The mean BLL for pregnant women in this study (59.5 ± 2.1μg/dL) was significantly higher ($p<0.01$) than that of non-pregnant women under similar conditions (27.7±1.1 μg/dL).[60] Given the high BLL of mothers in this study, pregnant women living in the Niger Delta may be suffering from clinical Pb poisoning. This suggests that Nigerian infants nursed by mothers with high body burdens of Pb may be at risk of neurological damage and impaired growth and development. This remains an issue, even though the mean levels of Cd, Ni, and Pb in the amniotic fluid of pregnant women were lower than the recommended limits in blood.[61]

In their study of multi-element analyses of human scalp hair samples from three distant towns in southeastern Nigeria, Nnorom et al. reported that geometric mean values of 65.4 μg/g (range 9.1 to 194.5 μg/g), 1.2 μg/g (0.4 to 6.6 μg/g), 26.4 μg/g (5.0 to 143.2 μg/g), and 35.1 μg/g (19.5 to 60.6 μg/g) were obtained for Pb, Cd, Ni, and Cr, respectively.[62] The study also showed that approximately 89% of the population had Pb levels >30 μg/g, and about 20% had levels >110 μg/g, a level which is considered critical.[62] The BLL concentrations amongst traffic wardens and police in different parts of Lagos were found to be 152.42 mg/dL in Oshodi, 148.56 μg/dL in Dopemu, and 122.6 mg/dL at the Ojota bus stop.[63] The latter values are higher than the 18.1 μg/dL average reported earlier by Ogunsola et al. in the same population, and represent a more than eight-fold increase of BLL in ten years.[64] Heavier vehicular traffic and consequent exhaust fumes are most likely responsible for the increased values.

Lead is well known as an environmental contaminant that can accumulate in various media, and thus actual lead exposure reflects both historical and current contamination. This gives rise to twin challenges: (1) obtaining updated information to gain an overall picture of exposure sources, and (2) predicting the internal body exposure levels and effects that occur under long-term exposure conditions.[65]

For decades, hair, primary and permanent teeth and nails analyses have been the primary non-invasive methods for calculating levels of metal exposures. This method allows for a more convenient way to monitor heavy metal exposure to children and adults on a much larger scale.[66]

Hair is considered to be suitable for comparative studies of environmental exposure in different age groups and populations; however, measured metal levels can be an undefined and non-uniform combination of endogenous and exogenous metals, depending on the washing methods applied before

Type of Sample	Chromium (Cr)				
	Location of Sample	Reported Concentrations	Author	Year of Publication	Reference Number
Canned Beverages	Nigeria	0.04 to 0.59 mg/L	Maduabuchi et al.	2007	91
Non-canned Beverages	Nigeria	0.01 to 0.55 mg/L	Maduabuchi et al.	2007	91
Human Scalp Hair	Nigeria	19.5 to 60.6 μg/g	Nnorom et al.	2005	62
Personal Care Products: Hair & Medicated Creams	Nigeria	0.383 mg/L	Ayenimo et al.	2010	79

Table 4 — Chromium concentrations in food products and human biological samples

analysis.[67, 68] Such complications pose problems with methods standardization, increased result variability, and data interpretation.[69] A CDC Expert Advisory Panel, in a bid to address these challenges, concluded that there is insufficient knowledge concerning the use of hair for the evaluation of exposure, along with a lack of adequate baseline or background values for populations.[70] Teeth, especially the primary teeth of small children (due to ease of sample collection and natural shedding), are believed to be the least dependent upon exogenous pollution of biological material.[71] However, BLL, as well as health status indices, appear to be more accurate for lead measurements than either hair or teeth, and thus are more widely used.

Cost Benefit Analysis of Lead Hazard Control

Children with high BLL require immediate medical attention. The literature is inundated with the detailed economic costs and risks of lead poisoning, including several analyses summarizing these costs and setting them against the estimated costs of lead hazard control.[72] Recent research has enlarged the understanding of the societal costs of lead poisoning. New studies have shown the correlation of lead poisoning with crime rates and their associated costs, as well as linking early lead exposure to adult-onset health problems.[72] Treatment for low BLL entails continuous monitoring of blood levels and prevention of further exposure, whereas high BLL requires chemical chelation to leach lead from the body; an expensive, time-consuming, painful, and sometimes dangerous and unsuccessful procedure. Kemper et al. provided the most comprehensive assessment of health care costs in the United States.[73] The investigators estimated the costs of screening and treatment as follows: venipuncture ($8.57), capillary blood sampling ($4.29), lead assay ($23), risk assessment questionnaire ($2), nurse-only visit ($42), physician visit ($105), environmental investigation and hazard removal ($440), oral chelation ($332), and intravenous chelation ($2,418). In addition, as children's BLLs increase, medical costs increase as well.[72]

Due to their slower development, lower educational success, and related behavioral problems, children with high BLL often require special education. Schwartz found that 20% of children with BLL > 25 μg/dL needed special education and suggested that the needs of these children span an average of three years, requiring assistance from a reading teacher, psychologist, or other specialist.[74] Reducing BLL in this population could reduce the number of children that require special attention. The recent lead poisoning in Zamfara State, Nigeria put a financial burden on donor agencies such as Médecins Sans Frontières (MSF), the WHO, and the Nigerian Government. Although children with lead-related cognitive deficits may not require special educational assistance, their losses can also be substantial in monetary terms, as impaired cognitive function can reduce individual productivity in society.[75]

In Nigeria, the lack of diagnostic data on the frequency of lead and other metal toxicities and non-control mechanisms for heavy metal pollution are a joint problem facing public health. A study by Ogunseitan and Smith provided cost-benefit information for environmental policy makers in Nigeria by employing a quantitative comparison of the health cost of the lead-related disease burden and the cost of a national lead abatement program.[74] The study found that if Nigeria were able to decrease the national BLL average by 5 μg/dL, the country could potentially gain more than $1 billion in savings annually from childhood health costs.[74]

Sources of Cadmium in Nigeria

In addition to lead, cadmium is of great concern in Nigeria. In a study examining metal levels in chicken eggs and local chicken feeds purchased from poultry farms, local markets, and the roadsides in Nigeria, a strong, positive correlation was found between cadmium levels in chicken feed and corresponding levels in the eggs.[16] In that study, the overall average concentration (mg/kg) of cadmium in eggs was 0.07, and the average estimated daily intake of cadmium was 2.4 µg.[16] The concentration of cadmium in chicken eggs in Nigeria is higher than in other countries.[16] Therefore, the estimated daily intake of cadmium in Nigeria slightly exceeds the normal reported daily intake of cadmium from eggs in some other countries.

Ground water cadmium concentrations in rural settlements in Southwestern Nigeria range from 0.24-0.36 mg/L, exceeding the WHO-recommended thresholds of 0.003 mg/L for potable water.[76] In addition, high concentrations of cadmium have been found in airborne cement dust around Sagamu, Nigeria [0.004-0.026 g/m3].[77] Cadmium concentrations in soil samples in Warri, Nigeria and surrounding environs were found to be between 7.605-24.194 mg/kg; substantially higher than the acceptable levels of 3 mg/kg for polluted soils.[78] In addition, high levels of cadmium (0.553 mg/L) have been found in Nigerian hair and medicated creams.[79] Prolonged use of soaps and creams containing heavy metals may pose a threat to human health and the environment.[79-80]

Biomonitoring of Cadmium in Nigeria

In a study on liver and kidney function tests amongst paint factory workers in Nkpor, Nigeria, Orisakwe et al. reported a level of 13.00 (± 1.00) µg Cd/L, as well as the possible long-term deleterious effects of heavy metals amongst occupationally exposed painters in Nigeria.[57] Ibeto and Okoye detected cadmium in 85.42% of the population sampled in southeastern Nigeria, with concentrations between 0.007-0.293 µg/dL.[81] These levels were substantially higher than the WHO permissible level of 0.0003-0.0012 µg/dL and higher than those obtained in developed countries.[82] To compare, blood cadmium levels in men and women in Spain were between 0.002-0.0324 µg/dL, and adults living in New York were reported to have a mean blood cadmium concentration of 0.0077 µg/dL.[83,84] Elsewhere in Nigeria, similar high blood cadmium levels have been documented. Arinola et al. reported a plasma level of 0.06 µg/dL in male adults in Ibadan, and a mean concentration of 9 µg/dL for adult men in Nkpor and Nnewi (Anambra State, southeastern Nigeria).[85, 57] An even higher blood cadmium concentration (0.76 µg/dL) has been documented in Akure, Ondo State in the Southwestern Nigerian region.[86] The mean blood cadmium level of pregnant women/nursing mothers in southeastern Nigeria was 0.99 (± 0.64) µg/dL, while that of non-pregnant women was .80 (± 0.46) µg/dL, with ranges between 0.1–2.8 and 0.1–2.9 µg/dL, respectively.[81] These values were higher than the mean blood cadmium concentration reported for pregnant women in Bangladesh, which was 0.012 µg/dL.[87]

Sources of Nickel and Chromium in Nigeria

In the same study that evaluated cadmium levels in chicken eggs and local feed, a strong positive correlation was found between nickel levels in the feed and corresponding levels in eggs.[16] The overall average egg concentration of nickel was 0.03 mg/kg, and the average estimated daily intake of nickel was calculated at 0.9 µg per person.[16] Heavy metal analysis of personal care products in Nigeria showed high chromium levels (0.383 mg/L) in hair and medicated creams.[79] The recommended daily intake (RDI) provided by the US National Research Council for trivalent chromium ranges between 0.05–0.2 mg/d, while the RDI for nickel is 1.4 mg per day for a 70 kg adult.[88-90] However, controversy remains regarding the essentiality of trivalent chromium and nickel for higher mammals.

Maduabuchi et al. documented that 68.9% of all non-canned beverages had chromium levels that exceeded the US EPA's MCL of 0.10 mg/L; 76.2% of canned beverages had chromium levels that were greater than the MCL.[91] For these studies, the concentration range of total chromium in canned beverages was 0.04 to 0.59 mg/L and 0.01 to 0.55 mg/L for non-canned beverages.[91]

Conclusion

Taken together, current indications from the few studies carried out specifically on Nigerians of any age reveal high BLLs. In Nigeria, sparse human biomonitoring (HBM) data have been collected over the last few years in areas polluted with lead, coupled with the absence of national reference values. Biomonitoring of BLLs in pregnant women in Nigeria should be considered critical to health care management, public health decision-making, and primary prevention activities. There is a clear need for study of the toxicological implications of chronic low-level exposure to heavy metals from African markets. A multidisciplinary approach composed of pediatricians/physicians, toxicologists, chemists, politicians, and social workers is recommended to address metal pollution in Nigeria. A specialized center managed by a multidisciplinary team of experts may be able to address the needs of individuals with a BLL > 20 µg/dL.

Such a center could provide input on the residential environment, possible sources of lead exposure, and socioeconomic and housing conditions of individuals living in contaminated areas.

As human biomonitoring is a vital tool for assessing and evaluating the past, current, and future influence of the environment on human beings, it is essential that such studies are performed in a fast, reliable, and cost-effective manner.

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